Phase 1-Development of a Probabilistic Technique for
On-line Parameter and State Estimation in Non-linear Dynamic Systems

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The overall goal of the project is to develop the software that will allow the implementation of a recently developed probabilistic technique formodel-based parameter and state estimation in nuclear plant dynamic systems. The methodology is based on the representation of the system dynamics in terms of transition probabilities between user specified sets of magnitude intervals (or cells) of system parameters and state variables during user specified time intervals. These choice of cells (or the partitioning scheme) may reflect the uncertainty on the monitored data or modeling uncertainties in general. It yields the probability distributions of the state variables/parameters to be estimated over the cells that partition the state/parameter space. Some advantages of the technique over the existing approaches are that it : a) allows flexibility in the choice of the system model that can be used (e.g. differential equations, difference equations, neural nets), b) can account for uncertainties in the monitored system state, inputs and modeling uncertainties through a probabilistic representation of system evolution, c) yields a likelihood ranking of possible system states, and, d) can be coded as a system-independent algorithm. As a specific application, the development targets real time estimation of global xenon evolution in a pressurized water reactor (PWR).

Phase 1 of the project addresses concept development and consists of two tasks. The objectives and accomplishments of these tasks are described below.

Objective 1 :
Development of a reduced order model that can predict xenon evolution in the core given all the initial conditions and model parameters (7/1/1998-6/30/1999).

Accomplishments : The dynamics of xenon evolution in a nuclear reactor core is well known, provided that all the reactor physics parameters and initial conditions are known. On the other hand, initial conditions for the governing equations during a transient are not generally known since the determination of these conditions requires the simulation of reactor operation from the beginning of the cycle. Also, it is difficult to estimates some of the relevant Parameters from first principles. Efforts towards Objective 1 first concentrated on the survey of the literature to identify the models used to date for dynamic xenon estimation purposes. It was found out that while mostly one-group, multi-region models have been proposed for spatial xenon estimation and control purposes, one-group/one-region models have been satisfactory to predict global changes. A one-group/one-region xenon model consisting of 3 first-order non-linear differential equations (power/flux, iodine and xenon) was identified as a potential candidate to be used for the estimation process. Externally inserted reactivity is the forcing function for the model and the model accounts for temperature feedback, as well as xenon induced reactivity changes. In order to validate the usability and applicability of the model, the following activities were carried out:

A set of experiments were performed at The Ohio State University Research Reactor (OSURR) to determine the system-dependent model parameters (which include core averaged macroscopic fission cross-section, temperature coefficient of reactivity, conversion factor from xenon density to reactivity and space/energy averaged microscopic xenon absorption cross-section) that can be obtained from operational data, as well as to investigate the sensitivity of the model to leakage. The experiments were performed following a 7 day shutdown of OSURR to assure an initially xenon free core (and hence known initial conditions). The preliminary analysis indicates that: a) it may be possible to obtain all the model parameters experimentally from xenon reactivity worth data as a function of time

following a reduction in power from equilibrium conditions to near zero level, and, b) while the model does not explicitly contain a neutron leakage term, the model fits the experimental data well. Since the OSURR has a high-leakage core (like most research reactors), the last finding implies that the model should be also applicable to PWRs due to their larger core size (and hence less leakage). Further work is underway to confirm this analysis through independent data generation from OSURR as well as using data from commercial power reactors (see Item 2 below). Also, other experiments are being planned at OSURR are being planned for testing the model under fast transients.

It may not be feasible to duplicate the experiments performed at OSU in commercial power reactors. For example, while it is possible to achieve a xenon free core at the startup of the new cycle, model parameters then determined will change with burnup and the reactor cannot be shutdown for extended periods due to economic reasons. In that respect, contacts were made with the Oconee plant (Seneca, SC), Davis-Besse plant (Oak Harbor, OH) and Perry plant (Perry, OH) to investigate the type of data that may be obtained from these plants in the course of normal operation to update the model parameters. Oconee and Davis-Besse reactors are similar 900 MWe Babcock&Wilcox PWRs and the Perry reactor is a 1200 Mwe General Electric BWR/6. Arrangements have are been made with the Perry and Davis-Besse plants to use their simulators during Summer 1999 as well as obtaining operating data. Reactor physics data from Oconee may be also available to determine the model parameters.

The only plant variables in the model that can be monitored are power/flux and externally inserted reactivity. In order to assure that the xenon concentration as a function of time can be estimated with these variables, the model was linked to the algorithm (see Objective 2 below) and a series of tests were run for with different operating ranges and initial conditions. The power/flux signal was simulated through the integration of the model equations using a 4th order Runge-Kutta scheme. The results showed that the estimation scheme could keep track of the xenon concentration in real time with tight convergence, however, there was relatively large uncertainty on the estimated iodine levels. The source of this uncertainty is currently being investigated by successively refining the partitioning scheme (the theoretical basis of the methodology assures single cell convergence in the dynamic variables to be estimated for a sufficiently fine partitioning scheme), as well as by a case specific estimation algorithm to eliminate possible errors in the linking process.

The computational time for the estimation process increases with the refinement partitioning scheme, due increased number of times the 3-equation xenon evolution model needs to used. In that respect, an adaptive neural net model of the xenon evolution was also developed under the assumption that all model parameters to reduce the computational time in the estimation process under the assumption that all model parameters are known (see Item 1 above). The model equations were used to train the net. A 10-fold reduction was observed in the estimation time. The adaptive neural net is being extended to include the situation that some of the model parameters (currently temperature coefficient of reactivity, conversion factor from xenon density to reactivity) are also to be estimated.

Objective 2 : Development of the algorithm that links the model developed under Objective 1 to the estimation procedure (1/1/1999-12/31/1999).

Accomplishments : In view of Phase 2 objectives of the project (i.e. the development and testing of the software that will allow linking the coupled model-estimation algorithm to the plant monitors), as well as its Phase 3 objectives (i.e. the development and testing of a system independent, user friendly, multi-tasking software), this algorithm was developed in a system independent, modular manner using object oriented programming. The software is written in Borland C++ to operate under Windows '95 (due to their wide usage) and can handle several systems (tasks) at the same time. The USER INPUT INTERFACE module sets up dialogue windows for the user to input the system equations and the state/parameter data. This module also sets up the configuration file describes the grouping and the order with which the tasks will be run. The COMPILE module compiles and links the algorithm, the system equations and Object Window libraries and outputs an executable file. On-line input and execution starts with the setup and initialization

of the task queue. In addition to system specific information, the task queue also contains information regarding the frequency with which the GRAPHICS module will initialize the display windows. The parent process sets up the tasks each of which is a child process and runs independently of the others. In the first pass for each child process, the appropriate algorithm is run with all the state/parameter space cell defined by the user specified partitioning scheme. In the subsequent passes, the software checks if sufficient time has elapsed for computing and plotting (user defined) before advancing the period index. Otherwise, the task is placed in the idle state waiting for the timer signal. At the beginning of each user defined data sampling period, the executable file reads the monitored data (currently simulated) and determines the state/parameter space cells they correspond to. The executable file then uses this information along with the previously computed probability distributions of the state variables/parameters to be estimated over the cells that partition the state/parameter space. The GRAPHICS module plots both these distributions and the 100% credibility interval for the estimated ranges of the system parameters and unmonitored state variables at the end of each sampling period. In addition to the xenon model developed under Objective 1 above, the software has been tested with two second order system models described by differential equations. As indicated in Item 3 under Objective 1, the estimation scheme could keep track of the xenon concentration in real time with tight convergence when all model parameters are known and only power/flux and externally inserted reactivity are monitored. In its current form, the software assumes that the system model consists of a set of first order differential equations. Model-algorithm interface is being expanded to accept discrete-time input-output models (e.g. NARMAX, neural net). Also, the multi-tasking nature of the software leads to relatively slow execution, mainly due to dynamic memory allocation and search for other tasks. Efforts are underway to speed-up these processes.